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ABSTRACT

Discussed are the nature of the development of conceptual relationships, and the structure of concepts. The topics are presented with regard to the importance of combining metaphors with two alternate approaches to learning, the first being rote learning and the other being inductive learning. The paper is intended to be a model of the concept of a concept, and to show how to think about instruction. (SA)

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TEACHING SCIENTIFIC CONCEPTS: The use of "Bottom Up" and "Top Down" Strategies Combined with the use of Metaphors.[1,2]

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Teaching scientific concepts...

One of my major assumptions about human cognition in general, and scientific thinking in particular, is that they are conceptual systems. Concepts are the tools of thought in that they enable us to slice up the world and make order of existing reality and to create theoretical explorations of phenomena which cannot be immediately perceived. Furthermore, concepts can be combined to create elaborate systems which have only an indirect relationship to the perceived events in the world.[1]

Some concepts designate real referents in the world-- "chairs", "trees", "houses", "dogs", etc., and these we term concrete concepts. Such concrete concepts help us to organize what I choose to label the middle size physical world. Even here we should be aware of the possibility of cultural differences. That is some cultures may make discriminations between phenomena that other cultures choose to ignore. Thus conceptual systems may vary from one culture to the next. Such conceptual variations would be detectable in the languages of these different cultures and ultimately in their patterns and possibilities of thinking. The relationship between language and thought in which language imposes structure or thought and may vary from culture to culture is known as the relativistic hypothesis or the Sapir-Whorf hypothesis after the linguists who first proposed it.

In most cases, however, we can find more similarity than differences in the way people choose to slice up the world. The reality of the external world does impose limits on our concrete conceptual structures. "Trees" are significantly different from "houses" and "dogs" to be conceptually separated from them. Whether a culture has a distinction between "trees" and "shrubs" or between "hardwood trees" and "softwood trees" is not as obvious. The eskimoes have several words for snow of different texture and moisture content

because it seems to be of major survival value to make finer discrimination. We begin to see these same types of discriminations being made by those in our culture who are most affected by snow--e.g. the skiers. But by and large the average man in Texas would not need and never use these fine discriminations. Consequently, if faced with snow of different types the Texan would be hard pressed to even notice the differences.

Let us now momentarily move away from these concrete concepts used to denote ostensible features and concrete events in the real world, to the more abstract conceptual systems which consist of scientific theories and mechanisms of thought. When we speak of scientific theories we are speaking of a conceptual system which purports to explain events in the world. Many of the concepts within this system are abstract in the sense that they have no specific observable referents. Thus they are meaningful only in terms of their relationships to other concepts. Thus concepts such as "genotypes", "entropy", or "the kinetic theory of gases", make sense in terms of other concepts which ultimately relate to more concrete concepts and to the real world. Evidence for "electrons" or "evolution" are only via a convoluted pathway of concepts and methods of investigation generated through our "conceptual spectacles".

Concepts constantly evolve and whole conceptual systems change over time. New concepts are invented so as to incorporate previously undetected relationships, and other less fruitful concepts become obliterated. Viewed in this manner we can understand all human knowledge and understanding in terms of the underlying conceptual systems that make cognition possible. The two dimensions of concepts discussed above are summarized in the following figure.

Place Figure 1 approximately here

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Abstract concepts at the top of the above hypothetical hierarchy are differentiated in terms of the concepts subsumed under them; while concepts at the bottom of the hierarchy are related to the real world and their differentiation occurs in terms of the finer and finer distinctions that can be discerned. One thing is clear: All concepts are related to other concepts. Only in some cases concepts are related directly to the real world in that they denote categories of real objects or referents. But even the concrete concepts gain additional meanings by virtue of their relationship to move abstract concepts within a host of different contexts.

I cannot hope to be immediately understood with respect to all of the above. I will thus try to provide several concrete examples in an effort to clarify the distinctions between concrete and abstract concepts and their dependence upon relationships which invest them with meaning, before going on to analyze the concept of a "concept". Nevertheless, I do hope that even now the <u>importance</u> of concepts as tools of thought is becoming clear.

Let us superficially inspect one abstract concept from the biological science so as to provide a general microstructure known as a semantic network. "Evolution" is abstract in the sense that it does not refer to any specific middle size physical object that we can perceive. Rather, it is an idea used to explain the current variety of forms of life and to explain from whence they came. Thus we can immediately link "evolution" to the concept of "variability" or "variance". How does such variability occur? Knowing the structure of the genetic material and the mechanisms of inheritance can enable us at this point in time to speak of changes in DNA known as "mutations". Thus we can link the concept of "mutation" to the concept of "variability". And we can link the concept of "DNA" to the concept of "mutaion". But there are

different kinds of mutation, some are "spontaneous" and others are "induced" and the "mutagens" causing changes can be specified. Furthermore, there are different types of changes in the DNA from "point mutations" to "gross abnormalities" in chromosome structure or number. all of these concepts-- "DNA", "chromosomes", "point mutations", "mutagens", and so on--can now be added to the "growing" network of concepts. We can now ask why the contemporary diversity of these specific organisms exist and not others. The concept of selection may be important for this explanation. Thus we can link "selection" to "variation" on the one hand and "evolution" on the other. Then the "environment" as an agent for selection may be added. But we know that within the environment are the agents of DNA change and thus "environment" would be linked to "selection" on the one hand and to "mutation" on the other. What are these environmental factors? We can now begin breaking up the environment into its components and these too are added to the growing network.

So as to distinguish that aspect of the environment that alters the DNA and that aspect of the environment that affect the total organism we may wish to provide ourselves with additional concepts. The concept of a "genotype" would be useful in speaking about the genetic coding at the chromosomal level. The concept of a "phenotype" would be useful in speaking about the actual manifestation of the genotype (i.e. traits). Now we can clearly specify that "mutations" occur in the "genotype" and are passed on from generation to generation whereas "selection" works upon the "phenotype" irrespective of the genetic make-up. These concepts can now be added to the network.

We could go on for many pages expanding and elaborating the network. However, this would be cumbersome and because of time restrictions, unnecessary at this time. The ideas expressed should suffice to make the point that all

concepts are ultimately related to one another and that meanings reside in these conceptual relationships. Furthermore, some concepts are abstract and have no meaning except in terms of conceptual relationships while others are more concrete. The concept map in figure 2 summarizes some of the above points but should be understood only as an example to demonstrate some of the ideas that we have been discussing. In fact this representation is very limited in scope and if developed only slightly more would become very quickly a blur of lines and words and be quite incomprehensible. Furthermore, on this representation the lines are not marked and thus the relationships remain unspecified. In reality the semantic network would not be complete without a clear understanding of what the lines represent and mean. Each line can be viewed as a "proposition". A proposition is a statement which expresses the relationship between two or more concepts and is either true or false. Thus the line between "mutation" and "DNA" may express the proposition: "mutations are changes in DNA". In essence there could be several different propositions expressing several different relationships between two concepts. Thus we would find the number of connecting lines or arcs proliferating again. For purposes of simplicity I have avoided these complications in the example of figure 2.

Place Figure 2 approximately here

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We can now theoretically picture whole disciplines as conceptual networks. Each concept as a center to a network and several networks overlapping with one another. Thus the "radiation" concept and "substances X,Y,Z" which appears in this tiny biological concept map have places in other concept maps from physics to chemistry, and so on. Again the central point remains that all subject-matter knowledge can be viewed as intricately connected and of a conceptual nature.

As science teachers we are concerned with the task of providing our students with conceptual frameworks. These conceptual frameworks will enable them to see and understand the world in a new and more powerful way. Consequently, students who have acquired a conceptual framework should be able to locate and address new problems and be able to solve them. These statements are too general to be of any use to you so I will endeaver to be more explicit. I will try to do two things:

1. Provide a more clear and concrete explanation of what concepts are.
2. Show how the task of teaching concepts can be accomplished based upon the analysis of the concept of a "concept".

THE STRUCTURE OF CONCEPTS

Up to this point I have spoken very generally about concepts. I have mentioned certain dimensions of concepts such as "abstractness" and "concreteness" but I have not been more explicit than that. What, for instance, is similar in "abstract" and "concrete" concepts? What makes a concept a concept? Furthermore, each of you has some vague notion of what a concept is. Thus let us try to reach a common denominator so that we can be sure from now on that we are talking about the same thing when we use the term "concept".

My first attempt at explanation is a very concrete and schematic presentation. This conic representation appears in figure 3.

Place Figure 3 approximately here

This is a structure of a cone, and the base and apex represent the two complimentory aspects of a concept: The extension and the intension.

The extension of a concept is no more than a class or category that is designated by the concept label (i.e. word). Thus for a concrete concept such as "chair" the extension would include all the possible referents that qualify as chairs. This is a very simplistic and all too rigid meaning of the concept of a "concept", or even for the "extension" of a concept, and as we shall see it will need to be drastically modified subsequently. Yet for purposes of instruction this type of a model will prove useful.

So let us continue building the model and move to the "intension" of concepts. The intension of a concept can be viewed as the "sameness" about all of the members of the extension. It may be what Plato meant when he spoke of his "ideals", or Kant's "Ding en Sich". By extracting the essence of the extension of a concept we end up with its intersion.

A more conventional way of viewing the intension of a concept would be to see it as a rule. The rule would enable one to distinguish members of the extension from the nonmembers. Thus the intension of a concept can be seen as a rule for categorization.

Thus we can see the intension and extension of a concept as two sides of the same coin. The extension elaborating the intension into its potentially infinite exemplers and the intension synthesizing all of the examples into a single rule of classification. As the conic figure shows we can label the movement from one dimension to the other in a simple way: When moving from the extension of a concept to its intension we can speak of "conceptualizing" whereas when we go from the intension to the extension we can refer to the process as that of "application".

In other words when one can take a wide array of phenomena or objects and find a commonality or regularity then we can say that he has conceptualized. And once conceptualization has been achieved then one can apply that knowledge by discriminating between instances that belong to the extension and those that don't.

So the conic representation of a concept gives us a simple way of speaking about concepts and what it means to acquire a concept and apply it. But this model is too simplistic and therefore incorrect. The reason is that concepts are not as clear cut as the conic model would lead us to believe.

First of all most conceptual extensions are fuzzy. That is, there are many instances or exemplers which can either be included or excluded from the extension. Secondly, most conceptual intensions defy definition. That is, we cannot exactly specify the rule for including exemplers in or excluding exemplers from the extension. This is true of all abstract concepts and most definitely of the most powerful scientific concepts.

But the fact that concepts are not "cut and dried" is even true of the most concrete concepts. The reason for this can be found in what Wiltgenstein called "word games". That is, the meaning of a concept is highly dependent upon the pragmatics of usage.

For example, we have a concept of "food". Are flowers food? Well that depends; some flowers are not food for human beings and others are. Furthermore those that are not may be food for some insects, animals, or other organisms. Or an even more striking example may be a skyscraper such as one of the twin towers of the trading center in New York City. We would all classify such a structure as a building. But what if a hypothetical giant came to town and decided to sit down and rest on one of these twin towers. If we were to ask

him what the twin towers were he may very well reply: "two chairs or two stools!".

The point I wish to make is that although the conic representation of concepts is a convenient and even a somewhat seductive way of speaking about concepts, we must take this metaphor of a cone with the necessary precautions and recognize that it is no more than a very simplified model.

The fact that concepts are neither finalistic nor "cut and dried" is of utmost importance. For it is precisely this flexibility which affects the potential richness of concepts and enables them to change. Such changes in concepts occur over long periods of time in the scientific disciplines, and over short periods of time within individual cognitive structures during episodes of meaningful learning.

Finally, I should stress that concepts are never really learned. Rather, they are progressively differentiated. For example, a first grader may have a concept of "energy" which is very simplistic (and permeated with misconceptions). A high school student would in most cases have a concept of "energy" which is more sophisticated than that of a first grader. A college physics major would have an even more sophisticated concept of "energy" than a high school student, but less sophisticated than his professor's; and so on. Thus we should be careful when talking about concept acquisition. Concepts are never acquired on an "all or nothing" basis. Concepts are not instantaneously acquired; one moment unknown and the next known. Rather, all concepts are slowly differentiated over long periods of time.

This is true not only of abstract concepts such as "energy". Even concrete concepts are progressively differentiated. Thus if I look at a table I recognize it as something that can be used to place things upon, to eat upon,

or to write upon. I may notice that it is made of wood and has four legs. But if an antique dealer looks at that same table he may recognize that it is a very valuable table for it is of a certain style of craftmanship and made of a very rare type of wood. In short the antique dealer's concept of furniture in general, and tables in particular, is far richer than mine.

Nevertheless, enough of an overlap between conceptual meanings held by different individuals does exist to enable communication. Thus people from a wide array of experiences can communicate with one another. But when experts get together and begin to talk to one another the novice is completely lost. The neophyte may even understand several of the words or labels used but he is incapable of comprehending the rich meaning which the concepts signify to the expert.

The purpose of education is to a large extent, to enable people in becoming experts. Thus the biology teacher who should be an expert in biology is interested in providing the students with biological concepts that will enable them to comprehend the discipline of biology. The major biological concepts will be progressively differentiated with the upshot of becoming an expert in biology.

How does the teacher teach concepts? Although the conic representation of concepts is, as we have witnessed, simplistic; we can use this model to begin speaking about the teaching of concepts.

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What needs to be emphasized is that all learning, if it is to be successful and useful over a long period of time, should be meaningful. That is, meaningful learning contributes to future learning, whereas rote learning will be less stable and of no future use unless perpetually rehearsed and overlearned.

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I wish to outline two alternate ways in which concept learning can proceed. These two modes are two extremes based upon the conic representation of a concept. Actually, all concept learning is a combination of the two modes.

The first mode of learning we will call "learning bottom up". Such learning is usually referred to as the inductive method. In our model it would refer to learning that occurs from the extension to the intension. That is after n exemplers of a conceptual extension have been introduced, the learner generalizes from those instances to the rule or regularity of the concept.

The second mode of learning is what we will refer to as "learning top down". This learning is the exact opposite of an inductive approach. Here the learner first learns the rule or regularity and is subsequently able to discriminate members of the extension from the nonmembers without ever experiencing them. This type of learning would at first sight seem more efficient because the learner is immediately led to the "essence" of the concept without having to go through numerous examples and then figure out their commonality.

In reality however, learning is always a combination of "top down" and "bottom up" learning. The sucessful teacher is one who first of all approaches the subject matter conceptually while using a combination of "top down" and "bottom up" methods. Approaching the subject matter "top down" would entail providing definitions or similar type explanations. The "bottom up" portion of teaching wuold be recognized as the provision of examples. These examples of what is to be considered part of the extension--ie. prototypes; or of clear cut instances of what is not part of the extension. These modes of teaching are embedded in Ausubel's theory in the form of A.O. and concrete props, respectively.

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Teaching conceptually cannot be summarized so simply for the same reasons that we gave before concerning the inadequacy of the conic model of concepts. We noticed that much of conceptualization is context dependant and contingent upon the pragmatics of problem solving and language usage. The concept teaching and learning cannot be simply summarized as either "top down" or "bottom up". Often teachers cannot simply define a concept nor give clear examples and must deal with borderline cases and very complex definitions.

The solution to these problems can be found in the use of other modes of explanation. Teachers often use analogies or models to explain scientific principles and themes that entail complex conceptual relationships. Instead of going into a detailed account of the available tools of explanation such as the simile, the analogy, the metaphor, the model, the allegory, and so on. I will simply place these techniques under the generic label of "the metaphor".

It has been said that our language is a "graveyard of metaphors". That is, each word at some point in time was a new way of experiencing and explaining relationships amongst concepts. And indeed, a metaphor is a way of providing new insights into the familiar. Often, when an old word seems inadequate to capture new relationships then a new word must be invented.

The initial pregnant metaphor is alive. It conveys multiple meanings and numerous possibilities. But over time, the meanings become better defined and the once living metaphor dies, taking its place in the growing "graveyard of language". Different sciences and disciplines have their own languages and their own living and dead metaphors. All scientific theories are complex models which are in fact, complex metaphors.

Students can learn science via the use of metaphors. Such metaphors can readily supplement the definitions and examples that we have dubbed "top down"

and "bottom up" concept acquisition, respectively. The talented teacher can explain the concept of a "gene" by defining and providing examples. But the additional use of metaphors such as the "genetic code" will provide an additional dimension giving the true rich flavor of science.

SUMMARY

In this paper I have tried to stress the importance of concepts in science education. I have provided a very simple and formal model of the concept of a "concept" and showed how this model can be used to think about instruction. I have also criticized this model and showed its weaknesses and inadequacies. Thus additional ways of teaching concepts were adumbrated.

The teaching of science can best be accomplished if it is conceptually oriented and accomplished via a combination of instructional and learning approaches. The approaches that I have proposed are "bottom up", "top down", and the use of metaphors.

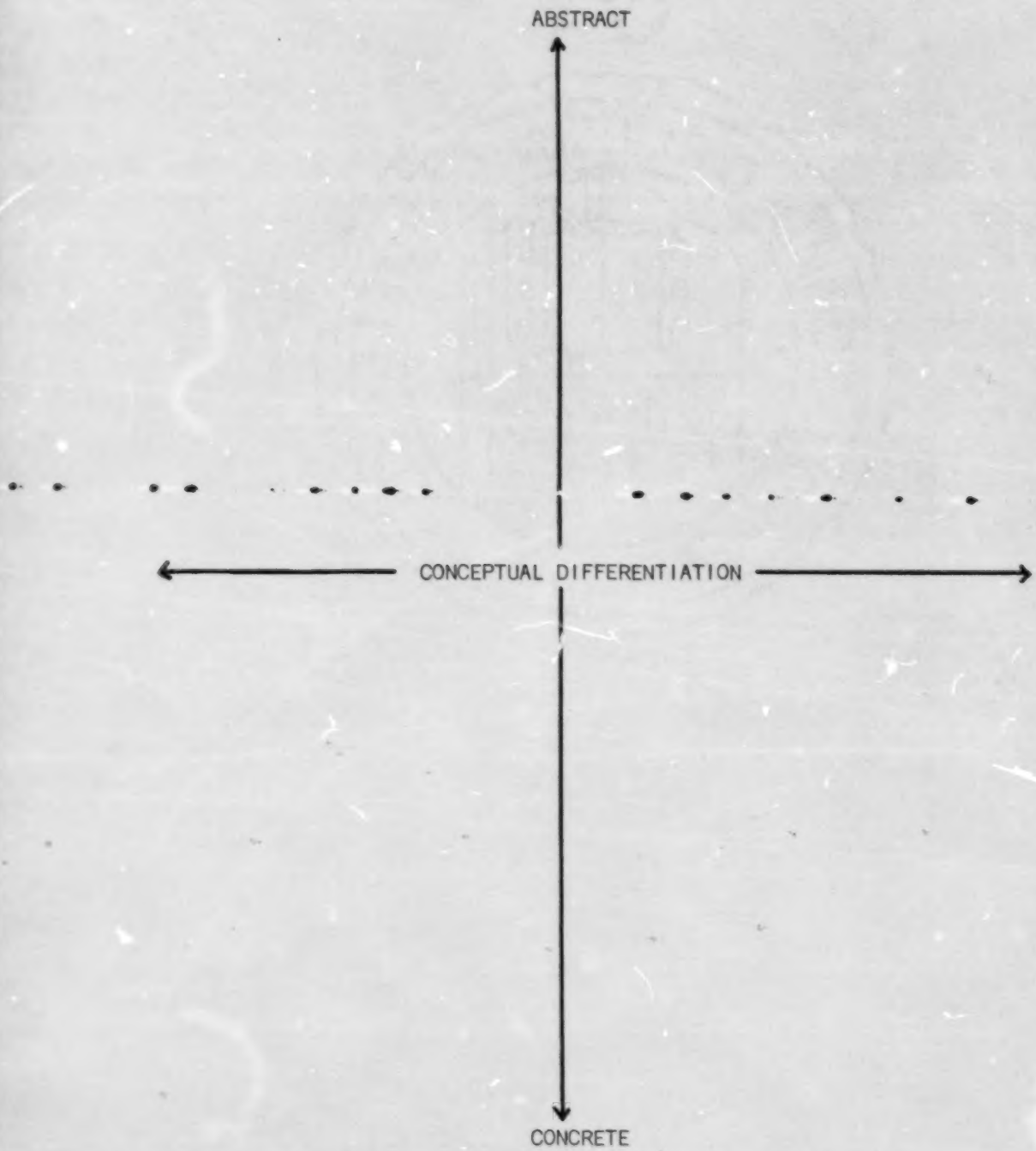

Figure 1: Conceptual Dimensions

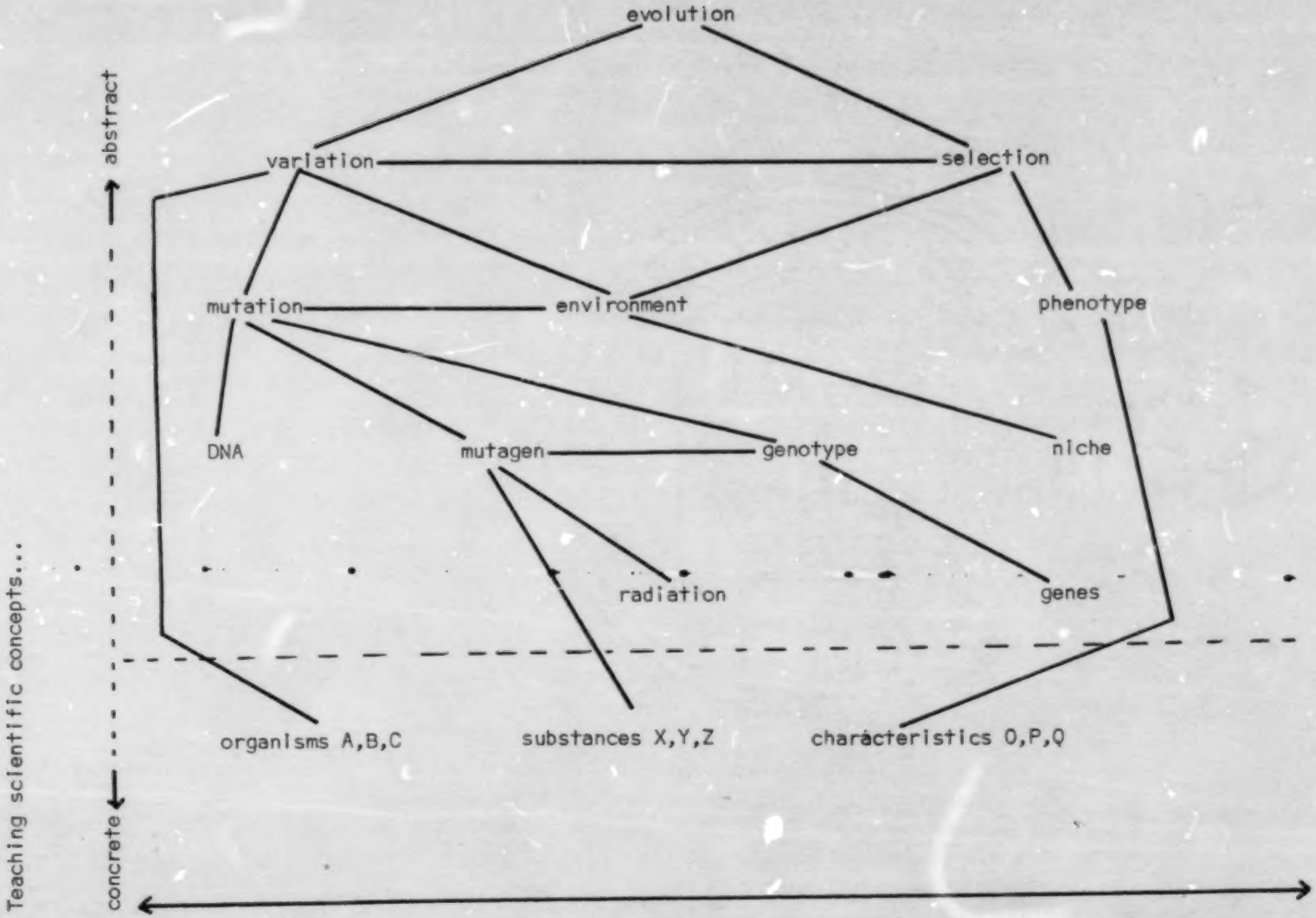

Figure 2: An exemplary semantic network

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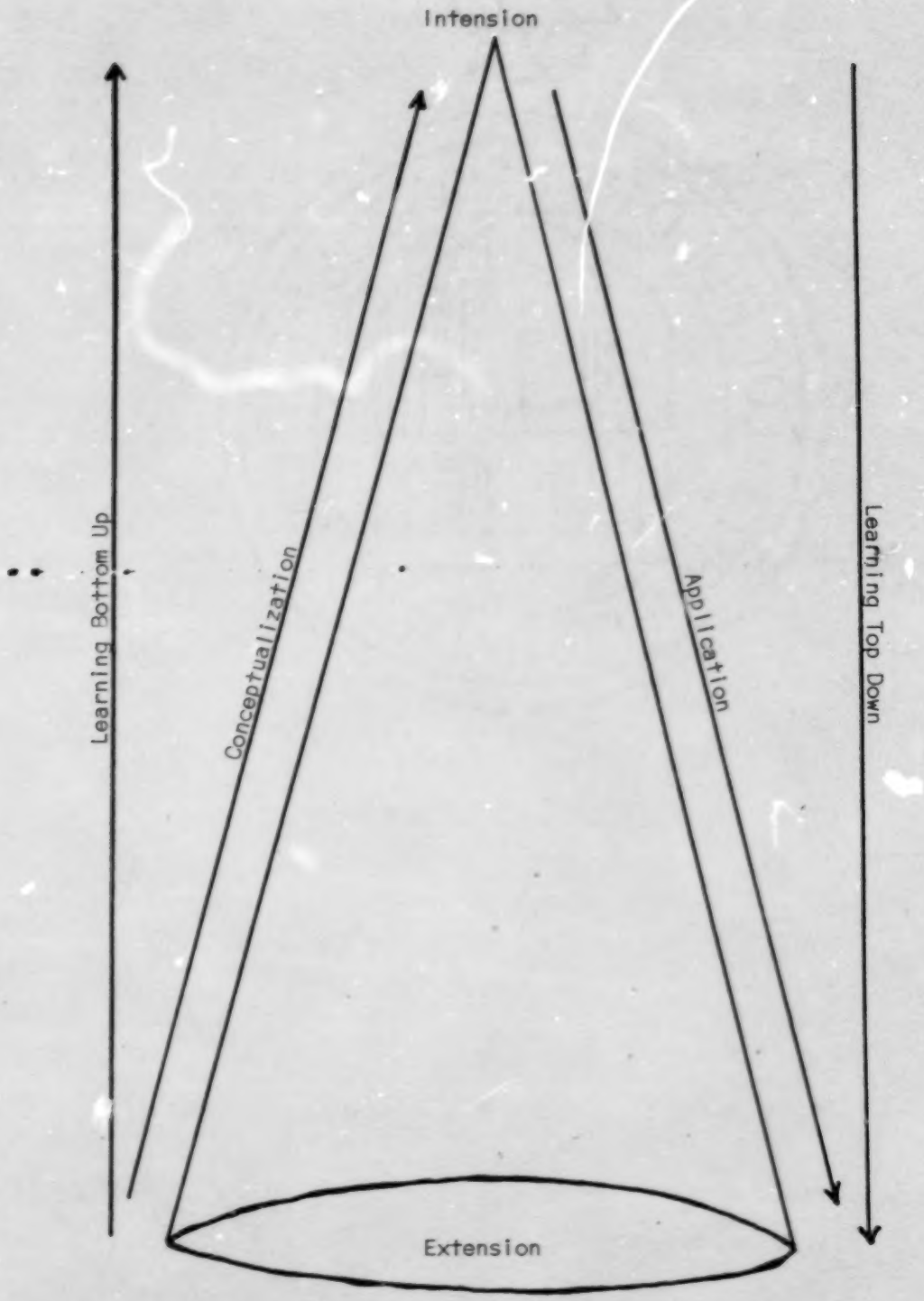

Figure 3: The schematic-conic representation of concepts